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COMPUTER MAPPING
as an aid in
AIR POLLUTION STUDIES

VOLUME TWO: INDIVIDUAL REPORTS

REPORT F
CONNECTICUT STUDY

by
John C. Goodrich
and
Paul Jack Dangermond

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16. Abstracts

A detailed report is presented of an air pollution study of State of Connecticut. The projects which comprise this study were initially undertaken because of their relevancy to other study regions and supporting efforts: (1) measured suspended particulates, for the southern New England Study, and the SYMAP correspondence course; and, (2) modeled and measured sulfur dioxide, for the modeling of the St. Louis and Boston Region studies. The report is divided into two sections; the SYMAP correspondence course, and modeling air quality.

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COMPUTER MAPPING

as an aid in

AIR POLLUTION STUDIES

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PREFACE

From July 1, 1968 through December 31, 1969, the Laboratory for Computer Graphics and Spatial Analysis conducted a demonstration of several conceptual, methodological, and technical approaches to problems in the field of air pollution, employing computer-produced maps and allied displays. This work was done under a grant (No. 68A-2405D) from the Division of Control Agency Development, National Air Pollution Control Administration (NAPCA), Public Health Service, U. S. Department of Health, Education, and Welfare.

The results of this study, taken in its entirety, should make an important contribution to the work of Federal, state, and local air pollution agencies, especially in their efforts to determine the best control strategies for use in air quality control regions. The computer is an ideal tool for relating and combining sets of data, and for considering alternatives. For instance, graphic displays can contribute significantly to the evaluation of both short-term and long-term control strategies.

In demonstrating "the use of computer graphics as a means for more clearly portraying data related to the sources, distribution, and community effects of air pollution," the primary emphasis was on case studies for specific areas. The secondary emphasis, to support and complement the case studies, included:

(a) "the development of instructional manuals covering the procedures required for the preparation and interpretation of computer maps of various kinds, as related to air pollution,"

(b) "the use of certain newly developed techniques for describing, analyzing, and portraying quantitative surfaces and movements relative to such surfaces, as related to air pollution," and

(c) "an appraisal of alternative equipment, techniques, and computer programs presently or potentially available for the production of computer graphic displays pertinent to air pollution."

The case study regions were selected in consultation with NAPCA. Considerations included:

(a) sufficient air quality, emission, and related socio-economic and meteorological data--spatially distributed over the region--to enhance the likelihood of adequately demonstrating the mapping techniques;

(b) representative problems in data handling and mapping so that the techniques demonstrated would have applicability to as many other areas as possible;

(c) special problems in data handling and mapping so that as many techniques as possible could be adapted, developed, and tested;

(d) areas of which NAPCA and the individual investigators had special knowledge and could therefore utilize relevant research to enhance the study;

(e) areas where an immediate interest in mapping had been expressed for on-going Federal, state, and local air pollution activities.

Other research was undertaken to support and complement the case studies, and, in particular, to provide:

(a) the widest possible distribution of the mapping programs and accompanying explanation of the techniques through

i) copies of the Laboratory's SYMAP Computer mapping program,
ii) an introductory correspondence course in the SYMAP program,
iii) general program description and supplementary explanation for the existing user-manuals;

(b) a general review of present and potential hardware, output devices, and programs applicable to computer graphic displays of air pollution and related data;

(c) means for predicting, projecting, and correlating air pollution and related data, utilizing the latest

knowledge in planning, geography, and spatial analysis in general;

(d) dissemination of information on approaches and techniques to Federal, state, and local air pollution agencies, especially for use in the air quality control regions.

The final report is divided into two parts: Volume One: Summary, and Volume Two: Individual Reports--the detailed reports on the case study areas and the technical reports related to other research undertaken. The pertinent graphic displays are included with the appropriate individual report and a complete set is provided with the Summary Volume.

Introductory sections describing the air pollution and related data used are provided in the major case study reports for St. Louis and Kansas City; these should be referred to by anyone unfamiliar with the types of data and problems existing in this field. Detailed discussions of special data handling and mapping techniques are presented either as appendices to case study reports, or in separate technical reports.

The Summary Volume includes a discussion of all the areas of research undertaken and contains the complete table of contents for the reports of Volume Two. This should provide a useful reference of the special problems and technical discussions of one report which may be of interest to the reader of another detailed report.

The Connecticut Study is presented here as Report F of Volume Two. It is divided into two sections--the SYMAP Correspondence Course and modeling air qua ity--in addition to an introduction discussing the base map preparation and air sampling network. An appendix of computer graphics produced is included.

The data used in the study was provided by the Connecticut State Health Department and the Travelers Research Center of Hartford, Connecticut.

The study was conducted by John C. Goodrich and Paul Jack Dangermond; the report was prepared by the investigators.

John C. Goodrich Editor
Cambridge, Massachusetts
April, 1970

REPORT F
CONNECTICUT STUDY

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1. INTRODUCTION

The projects which comprise the Connecticut Study were initially undertaken because of their relevancy to other study regions and supporting efforts:

i) measured suspended particulates, for the southern New England Study, and the SYMAP correspondence course; and,

ii) modeled and measured sulfur dioxide, for the modeling of the St. Louis and Boston Region studies.(1)

Although the data for Connecticut were only examined in passing, in retrospect it appears that this was among the most comprehensive air pollution information available, particularly in terms of the number and spacing of data point locations. This should be borne in mind in examining the computer maps produced for this study, particularly in relation to other studies.

1.1. BASE MAP PREPARATION

Several base maps were prepared for the state of Connecticut. One set of outlines and legends was used in conjunction with the data points and values for both the Connecticut Air Sampling Network data for suspended particulates and the Travelers Research Center data for air pollutant emission and measured and modeled sulfur dioxides. A second set of outlines and legends was adapted from previous SYMAP correspondence course lessons for use with the data points and values for suspended particulates.

The base map used for all but the correspondence course is shown in Figure F-1. The study area outline is the state boundary on the north, east, and west, but it is an arbitrary line on the south; this is purely to accomodate modeled air quality values which were calculated for points in Long Island Sound.[2] The southern boundary of the state is shown by a white line legend. Such features as state names and a graphic scale are also shown as legends.

There are five sets of data point locations used with this base map:

(i) Suspended particulates air sampling network; 24 points (Figure F-1), coded to the nearest town,

(ii) air pollutant emission grid cells; 875 cells, 260 of which fall outside the state boundary (Figure F-3),

(iii) test cases for modeled air quality; 100 receptor points (Figure F-4), located on a one mile grid,

(iv) test case of modeled air quality for verification; 53 receptor points (Figure F-5), and

(v) test case of observed values for verification, which also provides the points for comparing calculated and observed values; 46 points (Figures F-5 and F-6).

The outline and legends used with the SYMAP correspondence course exhibit about the same degree of detail as those used with the other base maps. In this case, the southern boundary of the state is used as a study area outline. Because some of the data for the correspondence course examples were missing, only 20 of the 24 data point locations were applicable. These can be seen in Figure F-2.

The x and y locations for the first set of base maps were measured in terms of an arbitrary one mile grid coordinate system used by the Travelers Research Center.(3) The coordinates were then converted by the SYMAP program user subroutine(4) to the appropriate map output measurements, in inches. The x and y locations for the base map for the correspondence course were measured directly from the source map shown in Example 2-1 in the row and column units of computer output;(5) the computer automatically transforms these units to the map output measurements, in inches. The listing of the x and y, or row and column, input is shown in Example 2-2.

1.2. AIR SAMPLING NETWORK

The state of Connecticut maintains a statewide monitoring network with measurements recorded for one or more pollutants in more than 20 towns. The data for the annual averages of 24 hour hi-vol readings for suspended particulates for 1966 and 1967 at 20 locations and for the first six months of 1968 at 24 locations were available for this study.

Figure F-1 shows the air quality surfaces for 1966 and the first half of 1968. Although the value ranges and symbolism used in the two maps are not quite the same, it is evident upon close examination that air quality significantly deteriorated from 1966 to 1968, according to the data mapped. For instance, in 1966 no area of the state exhibited readings greater than 115 micrograms per cubic meter; for the first half of 1968 7 of the 24 data points and about a third of the state exceeded this value (the three darkest levels of symbolism in the 1968 map). To avoid seasonal bias we would have to map the first six months of 1966 rather than the whole year. Note that, since all data points are contained within the state boundaries, the symbolism shown for Long Island Sound is only an extrapolation of the values along the southern boundary of the state. This can be misleading and values for this area should generally be ignored; they represent one estimate of the trend of the air pollution surface.

The upper left-hand illustration in Figure F-2 is a map of the same 1966 air quality surface shown in Figure F-1. The striking graphical differences between the two have to do with the (1) scale of the maps, (2) value range intervals, and (3) symbolism and use of white contour lines. On closer examination we can see that such distinguishing features as the area of highest value at Ansonia are clearly evident in both maps.

The upper right-hand illustration in Figure F-2 is the 1967 air quality surface. From the symbolism used we might conclude that the air quality had deteriorated drastically from 1966 to 1967; however, different value range intervals were used and the maps demand close examination. The highest

average value found for suspended particulates has actually dropped from 110 to 91 micrograms per cubic meter. The two lower illustrations in Figure F-2 show the percent change in suspended particulates from 1966 to 1967. The lower one third of the state--particularly in the southeast--does show improved air quality, while the northeastern part of the state exhibits the most deterioration in air quality, relative to the 1966 levels.

To actually quantify the change from 1966 to 1967 to decide whether or not air quality has deteriorated, we would need to compare the values for the two years at each computer character location and sum up the positive and negative differences, rather than the percent change shown in Figure F-2. We thereby weight all areas of the state equally and would find that slightly more of the state had deteriorated than had improved; 11 of the 20 data points show a relative deterioration. We could also weight our calculations by a variable such as population density to take into account the affected people as well as affected areas.

2. SYMAP CORRESPONDENCE COURSE

The Laboratory for Computer Graphics and Spatial Analysis distributes and administers a five lesson correspondence course designed to teach the basics of the SYMAP program to people with no prior knowledge of computer programming or the FORTRAN language. As a part of the demonstration grant efforts, the last two lessons of the course were significantly changed to reflect current data handling and information interests in the air pollution field.

The first three lessons acquaint the individual with the basic "packages" of the program, used to introduce information about

- study area outlines
- data point locations
- legends
- the values for mapping
- map size, scale, symbolism, etc.[6]

The final two lessons show the flexibility possible in determining the output characteristics of the map, such as the value range intervals to which the data will be assigned. They also demonstrate the application of the techniques to a real world problem.

The correspondence course was written in conjunction with Version 4 of the SYMAP program; since the mapping done in this study used the newer Version 5, some of the conventions and explanations shown in the course materials which follow do not apply and are superseded by instructions in the Computer Program Manuals.[7]

2.1. PROBLEM 4B

In the problem 4B of the SYMAP correspondence course written for air pollution specialists, the user was asked to prepare a base map for Connecticut using the directions, source map, and data point locations in the first three pages of Example 2-1. One of the three sets of values was then chosen for mapping. The final four pages of the example discuss, after the fact, what the user should have considered. The three maps referred to in the text are, respectively, 1966 air quality (upper left in Figure F-2), 1967 air quality (upper right in Figure F-2), and percent change from 1966 to 1967 (lower left in Figure F-2). The discussion, together with the three maps and corrections to his work, are sent to the user with lesson 5.

Example 2-2 shows the listing of the possible input to problem 4B. Using Version 4 of SYMAP, this set of punched cards would produce the map shown in the lower left of Figure F-2. All x and y locations are measured from an origin in the upper left of the source map (Example 2-1); by convention the first column of numbers shown for the outline, data points, and legends packages is the y (down, or row) measurement and the second column is the x (across, or column) distance. The 20 values for percent change, 1966 to 1967, are listed in the values package in the same order as they appeared in the table of data in Example 2-1; likewise, the data point locations are in the order of the numbers on the source map for Connecticut. If this convention is not followed, then the values will be associated with the wrong data point locations and an erroneous map will be produced.

Directions for Problem 4B

By now you should have a good grasp of the basic features of the SYMAP program for computer mapping. Accordingly, for the last of our map assignments under the introductory correspondence program, we are going to leave it to you to decide how to make the most informative map of Connecticut using a given set of air pollution data.

We will supply a source map, and three sets of air pollution data, each in a separate column. From these choose the column containing the set of data of greatest interest to you. We will also supply a few suggestions. Feel free to use other information available to you, if you care to do so.

The source map shows the location of 20 towns in the Connecticut air sampling network. The accompanying three sets of values are the average of the measured daily values for suspended particulates for 1966 and 1967, and the % change from 1966 to 1967.

You are to determine and draw in pencil on the source map appropriate borders from which to measure all coordinate locations. The outline of the study area should be approximated by you as you think best. (Incidentally, an outline may not cross a row more than 16 times -- a fact omitted from the introductory manual but conceivably of relevance here.) You will also, of course, have to determine the locations of the data points. (Be sure that your data points and the values you elect to use correspond in sequence.)

Include whatever legends you consider desirable. To minimize interference between legends and contour lines, only those legends deemed necessary should be placed <u>within</u> the study area. The locations of major cities should be included, but it is advisable to use symbols or abbreviations -- identifying them with a legend key located outside of the study area. The legend "Connecticut" should certainly be made prominent. Include a north arrow (pointing up in this case), a graphic scale, and the names of the surrounding states (New York to the left, Massachusetts to the top, and Rhode Island to the right). (The size of the source map is such that 100 miles is approximately equal to 8.7 inches.)

The entire F-MAP package is left to your discretion. Try to make your map sensible and informative, and suitable for a variety of other pollutants.

Example 2-1
Problem 4B Information

CONNECTICUT AIR SAMPLING NETWORK
SUSPENDED PARTICULATES (UG/M3)

SOURCE- CONNECTICUT STATE DEPARTMENT OF HEALTH
ENVIRONMENTAL HEALTH SERVICES DIVISION
AVERAGE OF DAILY LEVELS

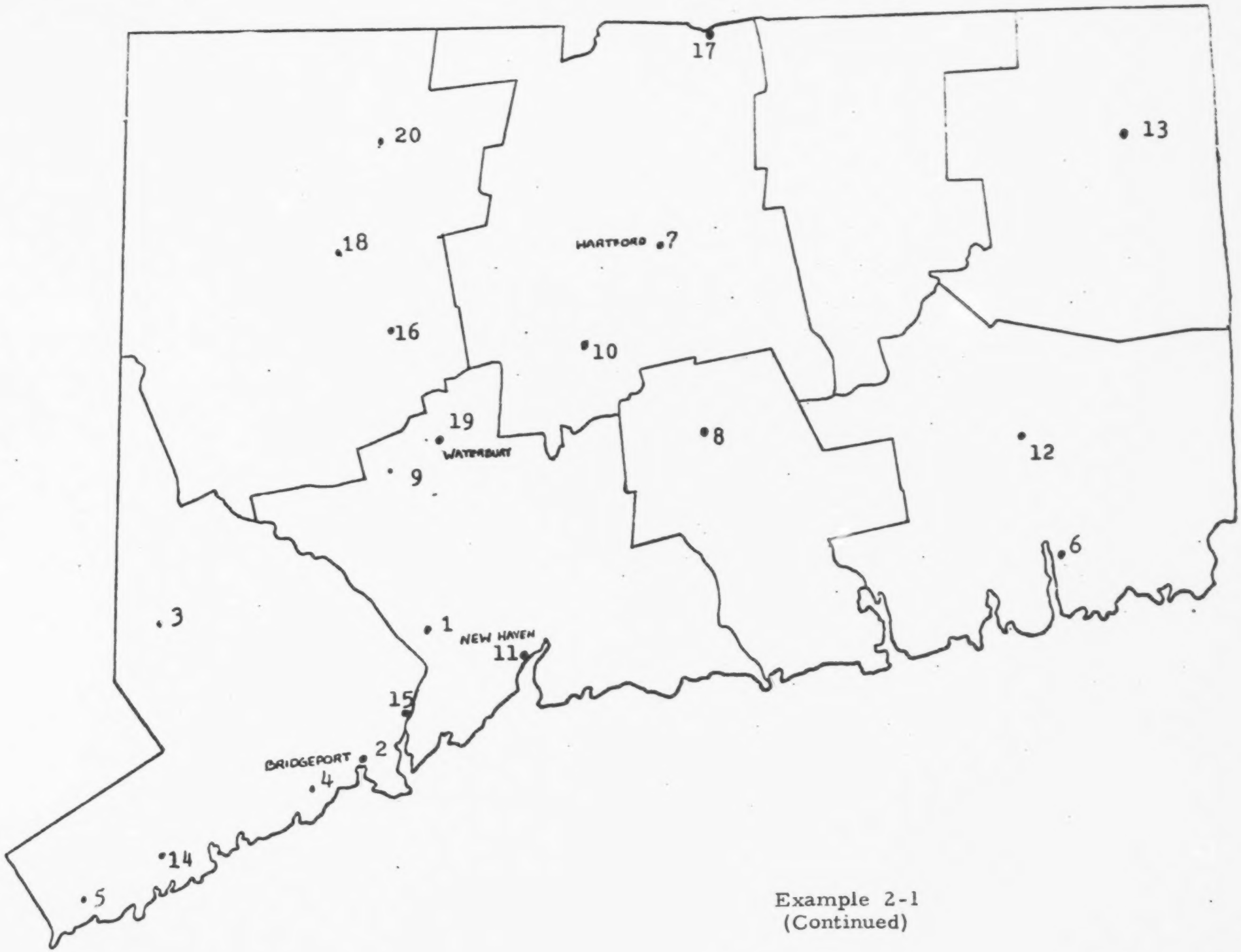
	STATION	1966	1967	PERCENT INCREASE
1	ANSONIA	110	88	-20
2	BRIDGEPORT	99	71	-28
3	DANBURY	56	72	28
4	FAIRFIELD	43	51	18
5	GREENWICH	68	71	4
6	GROTON	58	49	-16
7	HARTFORD	83	91	9
8	MIDDLETON	54	49	-9
9	NAUGATUCK	68	91	31
10	NEW BRITAIN	83	90	8
11	NEW HAVEN	93	86	-7
12	NORWICH	64	63	-1
13	PUTNAM	57	59	3
14	STAMFORD	92	80	-13
15	STRATFORD	46	51	8
16	THOMASTON	72	87	20
17	THOMPSONVILL	82	79	-3
18	TORRINGTON	44	57	29
19	WATERBURY	86	79	-8
20	WINSTED	46	82	78

DATA CHOICES FOR PROBLEM 4B

Example 2-1
(Continued)

PROBLEM 4B

CONNECTICUT SOURCE MAP



Example 2-1
(Continued)

Discussion of

PROBLEM 4B (Connecticut

This problem permitted and, in fact, required you to use your own judgement to a major degree. Decisions on all of the following were left entirely up to you:

1) The size of the map border.

2) The position of the study area within the map border.

3) The precise outline of the study area.

4) The location of the data points.

5) The reference number sequence of the data points.

6) The content of the legends to be used and their placement.

7) The map subject to be used, and its precise title.

8) The number of value levels to be used.

9) Whether contour or similar lines were to be used or omitted.

10) Whether histogram bars were to be used or omitted.

11) The text to be used.

12) Whether a contour type map or a proximal type map was to be used.

13) The general and data point symbolism to be used for each value level.

14) The background symbolism to be used beyond the study area.

15) The symbolism for contour or similar lines (if used).

The maps which are included herewith show our idea of a good way to represent the three subjects for which we made data available. These were all run in terms of a single base map, for the production of which we were required to make decisions on the first six of the above listed items.

Only the last of these six items (LEGENDS) seemed to require more than routine consideration. In addition to incorporating the several suggestions we ourselves made regarding legends, it seemed to be a good idea to place a blank before and after each city abbreviation -- so as to make such abbreviations slightly more conspicuous and easy to spot. We decided to provide by means of asterisks an indication of the adjacent shorelines of New York and Rhode Island, and of the boundaries between New York and Massachusetts and Massachusetts and Rhode Island. And we decided to provide a legend reading "LONG ISLAND SOUND".

What else might be desirable? Political boundaries and possibly rivers could, of course, have been shown as legends, but we doubted the value of doing so and felt that they would be more confusing than helpful (as well as somewhat time-consuming to provide). If ever needed, a transparent overlay could always be made later, showing at least the Connecticut outline and other identifying features.

Having decided upon and run our base map in terms of the first six items on the above list, we next considered the nine remaining items. In view of the straight-forward nature of the problem, the use of standard features seemed appropriate to us for all items where a standard existed. This quickly resolved Items 8, 9, 10, 13, 14, and 15 -- and there was, of course, no or little choice for us as to Item 7 (map subject and TITLE).

As to Item 11 (TEXT), we put in the source of the data. Normally we would have added at the end of the text the name of the person running the map.

As to Item 12 (type of map), we had to ask ourselves whether it would be wise to consider the proximal type of map, and whether contouring would be appropriate to our map subjects. As all of the data to be used was clearly quantitative, there appeared to be no good reason to consider seriously the use of the proximal system. That left only the question as to whether our data was suited to the use of contouring. If not, conformant mapping (not presented in this introductory correspondence program) could probably have been used to resolve the problem.

Under what circumstances would the contour type of map have been inappropriate and the conformant type suitable? Fundamentally, the issue can be reduced to this single question: Where change occurs between data zone averages, is actual change likely to be precipitous at the data zone borders? If so -- as, for example, with small-pox statistics among states with significantly different vaccination requirements -- conformant mapping (in which the change between data zone averages takes place at the data zone borders) is to be preferred.

In other words, if a value applicable to a data zone is the result of some policy, regulation, law tradition or other characteristic existing generally throughout that entire data zone, then change between that data zone and adjacent zones should be shown as taking place at the zone border -- and contouring should not normally be employed.

For the most types of quantitative information, especially air quality data, contouring usually provides a graphic medium of communication which is in fact more accurate than conformant mapping. For example, in the case of census tracts, enumeration districts, grids, air quality networks, and other purely statistical zones, data zone borders would have little or no effect on otherwise valid data -- and the more gradual slope of contouring would have a higher probability of approaching the true (but unknown) facts than the vertical precipices of conformant mapping. Where data may be affected to only a moderate extent, or in very few instances by data zone boundaries, then the advantages of contouring will usually outweigh the disadvantages.

Every map, made by every means, is to a greater or lesser extent schematic and employs conventions, and every map must be interpreted in the light of at least a general knowledge of how it is made and the conventions employed. No one type of map possesses all possible virtues. It is a question of using that type which is best for a particular purpose -- namely that type which combines a maximum of relative advantages with a mini mum of relative disadvantages or limitations.

Let us now examine our three maps as presented. Are they valid maps in terms of their subjects? What do they tell us? How accurate are they in detail?

Clearly they are schematic and general, as we have not given to the computer pertinent data on a square inch by square inch basis over the whole state. Such minute data, of course, does not exist -- but even if it did, we would not want to use it and could not afford to use it. Our maps present general trends -- which is almost certainly exactly what we want, and what we will find most useful. If we choose to use data from only a small number of locations because we seek a general understanding of conditions, or if we do not wish to undertake the effort and expense for getting more detailed data (on a fine grid, for example), then we have just what we want, and it is our responsibility to interpret it correctly. These comments apply equally to maps made by hand and maps made by computer. The computer will, in general, make fewer errors, and will contour more rationally and consistently than any human could.

On the map of 1966 air quality utilizing the standard elective, the range between 43.00 and 110.00 (data value extremes in micrograms per cubic meter) is divided equally into five levels.

If we are familiar with Connecticut we may be surprised to find the highest level 10 miles northwest of New Haven. We must recall that this map is based on only 20 sampling stations and the air quality at the station depends on its location within a given city. Looking further at this point, reference to the map border shows that this station is located in rows #41, column #34 and glancing at the listing above the map showing percent change from 1966 to 1967 we find that it is the first data point from the data originally furnished with problem 4B. The name of this station is Ansonia. The urban station in Ansonia had the greatest average for the year 1966 and thus the highest level appears in this area. In 1967, readings averaging 90 or 91 micorgrams per cubic meter are found for Hartford, New Britain and Naugatuck. Thus on the map for 1967 we find a much larger area in the highest level than in 1966. This does not mean that air quality drastically deteriorated from 1966 to 1967 but rather that a larger portion of the state falls into the highest twenty percent of the range of data for that year.

Perhaps more than anything else, this map depicting air quality only one year later points up the need for assuring that the sampling network is reliable and adequate computer mapping helps us identify areas where additional air quality monitoring is needed.

Example 2-1
(continued)

In our third map, we are considering the % change of particulate concentration from 1966 to 1967 and here the comparison of air quality in the two years becomes much more evident. The data value extremes show that this concentration at one station declined by 28% and at another increased by 78%.

Is it surprising to know that the greatest increase did not occur in the area of highest particulate concentration?

We notice, in fact, that the Ansonia area (which had the highest reading in 1966) shows an improvement in air quality, but that the northwestern part of the state (where readings were low in 1966) had the greatest relative deterioration in air quality.

In terms of our Connecticut maps, note how contouring at times greatly aids comprehension by tying together several peaks of highest value into a ridge of relatively high value, thereby stressing relationships and facts which might otherwise be less apparent. This is especially true with the high readings at Hartford, New Britain, and Naugatuck for 1967. Note how intervening contour levels between data points frequently make relative height much clearer. Another value of contouring is that the location of the contour lines in relation to data points frequently tells you a good deal about the values at data points -- usually, at least whether the value at any given data point is high, low, or middling in terms of the applicable value level. Such information is completely lost with conformant mapping, as an identical result is achieved regardless of whether the value is at the extreme lower limit or extreme higher limit or its class interval.

In closing this discussion, we call your attention to what is printed above the map showing percent change. Corresponding information is printed above every map by the computer -- but it has not been included heretofore in our reproductions in order to avoid having too many new things to speak of and explain all at once -- as well as to reduce the size and cost of our various exhibits. Note that the precise value for every data point is given to two decimal places -- just in case that much refinement should ever be helpful to the map user.

Example 2-1
(continued)

1.

A-OUTLINE X 8. 10.

5.	14.
5.	46.
7.	46.
7.	48.
5.	49.
5.	56.
6.	57.
5.	58.
5.	94.
36.	94.
37.	92.
39.	93.
40.	91.
39.	90.
40.	89.
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39.	86.
41.	84.
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52.	26.
53.	19.
54.	19.
56.	14.
57.	13.
56.	12.
57.	11.
57.	10.
58.	7.
53.	4.
47.	15.
43.	12.
5.	14.

Example 2-2
Problem 4B Input Listing

```
99999
B-DATA POINTS          X          8.          10.
                    41.          34.
                    48.          29.
                    40.          14.
                    50.          25.
                    56.           8.
                    37.          81.
                    19.          52.
                    29.          55.
                    32.          33.
                    25.          47.
                    42.          41.
                    30.          78.
                    12.          87.
                    54.          14.
                    46.          32.
                    24.          32.
                     6.          55.
                    19.          28.
                    30.          35.
                    12.          31.
99999
C-LEGENDS
     1    12              *
     2    12              *
     2    44              MASSACHUSETTS
     3    12              *
     4    13              *
     6    95              *****
    15    97              R
    16    97              H
    17    97              O
    18    97              D
    19    52    54          H
    19    97              E
    21     6              N
    21    97              I
    22     6              E
    22    97              S
    23     6              W
    23    97              L
    24    97              A
    25     6              Y
    25    97              N
    26     6              O
    26    97              D
    27     6              R
    28     6              K
    30    35    37          W
    39    99              *
    40     6              *
    40    94              * ***
    41     5              ***
    41    94              **
    42     4              *****
    42    40    43          NH
    43     3              *******
    44     4              *****
    45     4              NORTH
```

Example 1-2
(Continued)

3.

```
   48    29    31        B
   48    62              LONG ISLAND SOUND
   51    82              H   > HARTFORD
   52    82              W   > WATERBURY
   53    82              B   > BRIDGPORT
   54    44              C O N N E C T I C U T
   54    82              NH > NEW HAVEN
   55    44              - - - - - - - - - - -
   57    82              0    5    10   15
   58    82              I------------I
   59     6              **
   59    83              MILF    SCALF
   60     5              *
   61     4              *
   62     2              **
   63     1              *
99999
E-VALUES                    X
                      -20.0
                      -28.0
                       28.0
                       18.0
                        4.0
                      -16.0
                        9.0
                      - 9.0
                       31.0
                        8.0
                      - 7.0
                      - 1.0
                        3.0
                      -13.0
                        8.0
                       20.0
                      - 3.0
                       29.0
                      - 8.0
                       78.0
99999
F-MAP
C    CONNECTICUT AIR  SAMPLING NETWORK
C   SUSPENDED PARTICULATES   (UG/M3)
C    PERCENT CHANGE 1966 - 1967
     1              8.0      10.0
     2              0.0       8.0        0.0        10.0
    10
SOURCE- CONNECTICUT STATE DEPARTMENT OF HEALTH
        ENVIRONMENTAL HEALTH SERVICES DIVISION
        AVERAGE OF DAILY LEVELS
9999
99999
999999
```

Example 2-2
(Continued)

2.2. PROBLEM 5A

Problem 5A builds upon the results of Problem 4B and is essentially self-explanatory. (See Example 2-3) With the discussion and output from Examples 2-1 and 2-2, the user is asked to specify meaningful value range intervals for the percent change in air quality from 1966 to 1967. This information is specified in electives 3 thru 6 of the map package of the SYMAP program.[8]

The listing of two possible map packages is shown in Example 2-4; the second map package was used to produce the map in the lower right corner of Figure F-2. By highlighting iso lines such as the 0% change contour, we can quickly visualize areas of the study area that have importance to us. It is from this map that we can ascertain that about one third of the state (as shown by the symbol "L"), particularly the southeast portion, showed an improvement in air quality from 1966 to 1967.

Directions for Problem 5A

The director of a division of NAPCA is interested in relative increases or decreases in Air Quality, as well as absolute levels for improving control programs. You have suggested that he might find computer produced maps of some value in making a preliminary assessment of the problem. By way of illustration, you have given him one of the air sampling network maps of Connecticut (provided with this lesson in the solution to problem 4B) entitled "percentage increase in suspended particulates, 1966-1967". He is interested in your idea and asks if you could run another map which would predict the effect of expediting abatement programs in critical areas. He feels he would be interested in those portions of Connecticut where:

1) air pollution did not increase from 1966 to 1967,
2) air pollution increased, but less than 15%,
3) air pollution increased at least 15%, but less than 35%,
4) air pollution increased at least 35%, but less than 50%,
5) air pollution increased more than 50%.

You will want to point out that this map shows air quality as a statewide issue and that analysis at a finer scale (e.g. for a single city) would require detailed local data. Here, data for only 20 sampling stations were available and changes from one year to another may be caused by normal sampling error and meteorological differences.

The director, nonetheless, feels that the map would be useful to them and would give them a better comprehension of the spatial aspects of the problem than they have heretofore been able to gain. Accordingly, you offer to run the map requested, as a trial run to precede his further, careful consideration of the entire problem.

You realize that there are several ways of meeting the requirements in a single map using available electives. In Problem 4B you prepared the full input for a map of Connecticut Air Quality measured at 20 monitoring stations. In Problem 5A you are to prepare two alternative ways of meeting the director's needs. Show the title and electives to be used in each case, using for the purpose the four F-MAP coding forms provided. Do not use elective number 7.

Example 2-3
Problem 5A Information

Discussion of

PROBLEM 5A (Connecticut II)

As the specified value range intervals are unequal, it is advantageous to make use of elective number 6.

The map of Connecticut was given to the NAPCA divisional director "by way of illustration". Accordingly your solution must be such as to apply to all parts of the country, and the precise values applying to Connecticut are not necessarily relevant.

This poses the necessity of your specifying, by means of electives 4 and 5, appropriate extreme values. One possible procedure would be to employ a total value range of 0% to 100% inclusive. There would then be four levels -- 0-15, 15-35, 35-50, and 50-100 -- and it would be necessary to use elective number 3, as five is the standard number of levels. Electives 4 and 5 could be used to specify respectively 0 for the minimum and 100 for the maximum -- and elective number 6 for the value range intervals.

There are however, some disadvantages to this procedure, the most serious being the fact that the pollution at some station might have gone down in some cases -- or have increased more than 100% in others. In other words, in terms of this problem, the frequently valid range of 0% to 100% has little significance for the upper limit in this problem. Accordingly, this solution is at best a very poor one. It would inappropriately stress the 100% point by printing the letter "H" in those areas computed to have a value of more than 100, whereas our two limiting criteria are less than 0% and greater than 50%.

Using elective number 5 to specify 50% as the maximum (instead of 100%), as in the second solution, would solve the difficulty at the upper end of the scale.

Of the two solutions listed, only the last would appear to meet the director's need in a satisfactory manner

If the use of elective number 7 had not been ruled out there would certainly be a number of additional possibilities to explore. But it would seem to us, that nothing of superior merit would be likely to result.

One possible approach would be to run four separate maps to show the incidence of air quality change above and below each of the four specified cut-off points (0%, 15%, 35%, and 50%). While this would cost more, and not comply with the specific assignment, perhaps it would be the best solution of all -- in that each map could be considered independently, with the consequences more clearly apparent than in terms of any single map.

Returning to the use of a single map, as assigned, one other possibility has occurred to us. In conflict with the first paragraph of this discussion, it would not require the use of elective number 6.

We refer to the possibility to employing electives 4 and 5 to specify a total range of 0% to 50%, and then using elective number 3 to specify ten levels with equal ranges of 5%. But this would make more distinctions than called for, and would therefore be less clear.

The map we provide seems to us to represent the best of all possible solutions to the problem as given. It has, however, one small technical defect, trivial perhaps but worth mentioning: the value of precisely 50% has been incorrectly included in level number 3. We should perhaps have specified 49.99 (or possibly 49.9999) for the maximum value under elective number 5. But, with a schematic map of this kind, going to such a refinement would probably have been unwarranted.

* * * * * *

Note that the locations of data points have LOW and HIGH values are designated by a period or a slash across the letters "L" and "H".

You may wish to compare our map provided for Problem 5A with the corresponding (third) map provided for Problem 4B. Both are divided into a total to five value levels. The general trends are similar, but as the contour intervals are significantly different, the contour locations must also be different. Both maps deal with the same conceptual surface, but varying the "height" of the contour levels varies the descriptive result. The occurrence of such variations, of course, constitutes the reason for employing electives 4, 5, and 6.

Observe the differences in the locations of the contour lines -- for example, in relation to New Haven and Norwich (in the Southeastern part of the state). Such differences may be of particular interest to NAPCA in developing its control strategies.

Example 2-3
(continued)

```
F-MAP
C    PERCENT INCREASE IN SUSPENDED PARTICULATES, 1966-1967
C    L = LOW (BELOW ZERO)    1 = 0-15 PERCENT    2 = 15-35 PERCENT
C    3 = 35-50 PERCENT    4 = 50-100 PERCENT
     1              8.0        10.0
     2              0.0         8.0         0.0         10.0
     3               4.
     4               0.
     5             100.
     6              15.         20.         15.          50.
    10
SOURCE- CONNECTICUT STATE DEPARTMENT OF HEALTH
        ENVIRONMENTAL HEALTH SERVICES DIVISION
        AVERAGE OF DAILY LEVELS
9999
99999
```

```
* F-MAP
C    PERCENT INCREASE IN SUSPENDED PARTICULATES, 1966-1967
C    L = LOW (BELOW ZERO)    H = HIGH (ABOVE 50 PERCENT)
C    1 = 0-15 PERCENT    2 = 15-35 PERCENT    3 = 35-50 PERCENT
     1              8.0        10.0
     2              0.0         8.0         0.0         10.0
     3               3.
     4               0.
     5              50.
     6              15.         20.         15.
    10
SOURCE- CONNECTICUT STATE DEPARTMENT OF HEALTH
        ENVIRONMENTAL HEALTH SERVICES DIVISION
        AVERAGE OF DAILY LEVELS
9999
99999
```

Example 2-4
Problem 5A Input Listing

3. MODELING AIR QUALITY

The Travelers Research Center (TRC) of Hartford, Connecticut developed a regional air pollution simulation model in 1967 and 1968 for the state of Connecticut.[9] One of the purposes of the model was to estimate the spatial distribution of air pollution concentrations across the state of Connecticut. As an input to the model, they estimated an hourly emissions inventory for the state's five major pollutants; sulfur oxides, nitrogen oxides, carbon monoxide, hydrocarbons, and suspended particulates. They also gathered information on meteorological and climatological factors relevant to the atmospheric dispersion processes over Connecticut.

In addition, TRC designed a model verification program. The simulation model was tested for accuracy against actual measurements for specified time periods; this provided feedback for improvement of the model. Since model verification was carried out for specified time periods (usually a few hours), the accuracy of the emission inventory, meteorology, and modeling procedures were very important. Most air pollution simulation models determine seasonal concentrations or the annual integrated case, and do not attempt to calculate air quality for such short time periods.

The computer graphics efforts of our study concentrated on mapping the modeled and measured air quality, comparing the two, and mapping pollutant emissions.

3.1. EMISSION INVENTORY

The source map used by the Travelers Research Center for both their emissions and air quality data employed an

arbitrary coordinate system of grid cells one mile on a side, oriented north-south and east-west. According to the coordinate system there were 105 cells horizontally and 75 vertically, for a possible total of 7875; of these approximately 5535 were actually within the state boundaries.

The SYMAP program can normally accept only 1000 data points for interpolation of a surface.[10] Therefore, it was necessary to aggregate the TRC cells to achieve a manageable number of data points. A program was written to aggregate sets of nine one mile cells into a new cell 3 miles on a side;[11] this resulted in 875 new cells, 615 of which were inside the boundaries of the state. At the scale of the mapping, virtually no detail is lost by this aggregation procedure.

Of the five pollutants inventoried, sulfur oxides and carbon monoxides were selected for mapping as representative of population and automobile related pollutants. In fact, the inventories for these pollutants were derived by applying proportionality factors to the population density and automobile usage patterns, respectively. Therefore, Figure F-3 shows the maps of population density and automobile usage for Connecticut; it also shows a first approximation of sulfur oxide and carbon monoxide emissions from line (mobile) and area (space heating) sources.

Although the use of such proportionality factors is useful for estimating population and automobile related emissions, far more detailed emission inventories are needed to do accurate microscale modeling.

3.2. CALCULATED AIR QUALITY

The TRC model divided the state up into some 5600 grid points, each a mile on a side; air quality could be calculated at any of these grid points. There were also many options for the time-averaging of ground level concentrations, vertical and horizontal mixing, and a variable wind field and emission inventory. The model was basically designed for the detail of day to day analysis, rather than seasonal or yearly averages.

The diffusion model was quite sophisticated in its use of a variable wind field. However, for stagnant conditions, even this model does not give results having a good correlation with air quality measured during the same period. Such a stagnant condition is shown for sulfur oxides in the first map of Figure F-4: a down valley (Connecticut River Valley) stable flow at noon time in October. It is evident from the symbolism used that the levels of air pollution are highest in the major urban areas of the state and spill out into Long Island Sound.

By contrast the second map in Figure F-4 shows the expected levels of sulfur oxides for a steady northwest wind at midnight in January. The predominant wind pattern shifts the highest levels of pollution from the urban core areas to down wind suburban and rural areas.

Comparison of these modeled air quality levels with actual measurements is essential to test the validity of the model calculations. Unfortunately, there are three sets of parameters which can affect the results:

(1) The emission inventory accuracy,

(2) the meteorological data and variable wind field used; this is particularly critical with stagnant conditions, and,

(3) the parameters in the model equations; for example the decay parameter influences how far downwind will the urban area pollution affect rural areas, as in the second map of Figure F-4.

Unfortunately, it is very difficult to design a verification program to isolate each of these three sets of parameters which may influence the modeling calculations.

3.3. CALCULATED VERSUS OBSERVED VALUES

The TRC verification program was commenced in the fall of 1968. Unfortunately, the timing of the program was such that computer mapping could be used for only a few of the tests. The maps for one such test are shown in Figure F-5.

On October 15, 1968 from 2 to 4 p.m. a 46 station statewide monitoring network for sulfur oxides was activated. A surface of air quality was mapped from these 46 2-hour readings and is shown on the right in Figure F-5. The highest reading was 0.124 parts per million (ppm); an instrument threshold value of 0.100 parts per billion (ppb) was used where readings of "zero" were obtained.

For the same time period, estimated emission inventory, and recorded meteorology, the TRC model was run to calculate sulfur oxides; calculations for the same 46 points (plus 7

additional receptor points) were mapped as shown on the left in Figure F-5. The highest reading calculated was 0.588 ppm and low values of "zero" were found by the model.

The two surfaces were then compared at the 46 measurement locations and the absolute differences between the observed and calculated values mapped. Difference surfaces are shown in Figure F-6. The surfaces were <u>not</u> compared directly; only values at the data point locations were compared. (12)

In the map on the left in Figure F-6 three categories of symbolism were used to show the differences between observed and calculated values;

(1) white areas; this shows the portion of the study area where the model is in close agreement with the observed values,

(2) dark areas (the 5 highest levels); this shows the portion of the study area where the model <u>over</u> calculates the level of air quality. This includes most of the major urban areas, and

(3) light areas (the lowest level--dots); this shows the areas where the model <u>under</u>calculates the air quality.

The degree of undercalculation is shown in the map on the right in Figure F-6. The white areas show the portion of the study area where the model overcalcualtes; the darker the symbolism the greater is the <u>under</u>calculation in absolute terms. 29 of the 46 data points had calculated values less than the observed ones; likewise, a greater portion of the study area (within the state boundary) is shaded than white.

From this one test case it is not possible to draw many conclusions. The model appears to be systematically overcalculating in urban areas and undercalculating in rural areas, for this set of inputs. To draw further conclusions, it would be necessary to design the tests so as to isolate the three sets of parameters which can affect the model results. Computer maps of such tests could prove to be very useful.

REFERENCES

(1) Discussion of these other studies is covered as follows:
- Southern New England Study - Volume Two, Report G.
- SYMAP Correspondence Course - Section Two of this report
- modeling, for St. Louis - Volume Two, Report C.
- modeling, for Boston - Volume Two, Report J.

(2) The Travelers Research Center (TRC) model calculated air quality values at selected points in Long Island Sound for appropriate wind directions; calculations were not made outside of Connecticut except in Long Island Sound. Consequently, the study area was defined to include the state plus appropriate portions of Long Island Sound. For convenience sake and for comparability, the same study area outline was used for all maps, although it would clearly be misleading to map emissions from grid cells over the water.

(3) The TRC model divides the state up into 5600 grid points, each a mile on a side. The Connecticut Air Sampling Network data was coded for mapping according to this coordinate system, in addition to the TRC data.

(4) For a discussion of the user-subroutine, FLEXIN, see Volume Two, Report K, Section 4--Computer Program Manuals.

(5) On the computer output produced by the SYMAP program there are 10 lines per inch horizontally and 8 lines per inch vertically; these are the same units used for measuring locations on the source map. Note that the origin is in the upper left corner. For a more detailed discussion see Volume Two, Report K, Section 1--Computer Program Manuals.

(6) These packages are discussed in Volume Two, Report K, Section 2--Computer Program manuals.

(7) The correspondence course is not being updated to Version 5 or expanded at the present time. The use of the new Computer Program Manuals will point out the correct specifications for Version 5 and show more advanced applications of the program; these manuals are contained in Volume Two, Report K.

(8) --elective 3: number of levels
--elective 4: minimum value of the range
--elective 5: maximum value of the range
--elective 6: intervals into which the range is to be divided, taking into account the constraints of electives 3 thru 5.

Values below the minimum specified in elective 4 are shown with a special symbol (the same is true for values above the maximum in elective 5). Volume Two, Report K, Section 3 should be consulted for a detailed discussion of the map package electives

(9) The work undertaken and the modeling procedures are discussed in:

Travelers Research Center, Inc., "A Final Report to the Connecticut Research Commission on the Development of a Simulation Model for Air Pollution Over Connecticut", Vol. I: Summary Report, Grant No. RSA-67-4 Connecticut Research Commission, 250 Constitution Plaza, Hartford, Connecticut, and

Travelers Research Center, Inc., "Connecticut Air Pollution Simulation Model", Grant No. RSA-67-4, 250 Constitution Plaza, Hartford, Connecticut (October 12, 1968).

(10) In more recent versions of the program more than 1000 data points can be used, but with a commensurately increased cost. Also, the GRID program can be used for cases like this where input is in the form of uniformly spaced grid cells and the interpolation algorithm of SYMAP is not necessary. However, for the purposes of this study we assumed (1) use of a version with the 1000 data point constraint and (2) use of only the SYMAP program.

(11) This cell aggregation program was the predecessor of the more complicated MELD program used in the Puget Sound Region Study; see Volume Two, Report H. A sorting routine was not necessary since the cells were originally in a sequential order.

(12) See the Puget Sound Region Study (Volume Two, Report H) for a more extensive discussion of difference maps.

APPENDIX

COMPUTER GRAPHICS

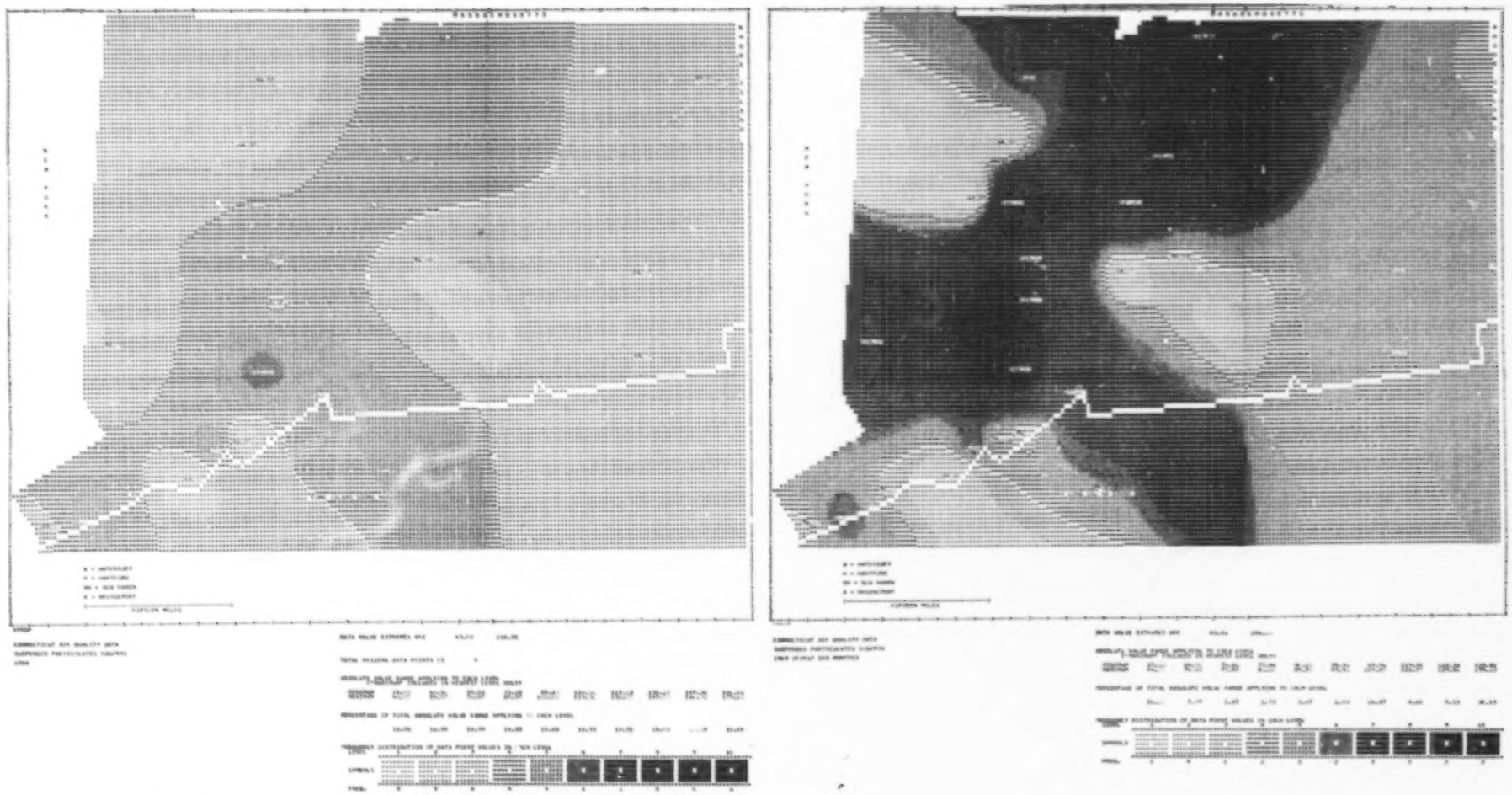
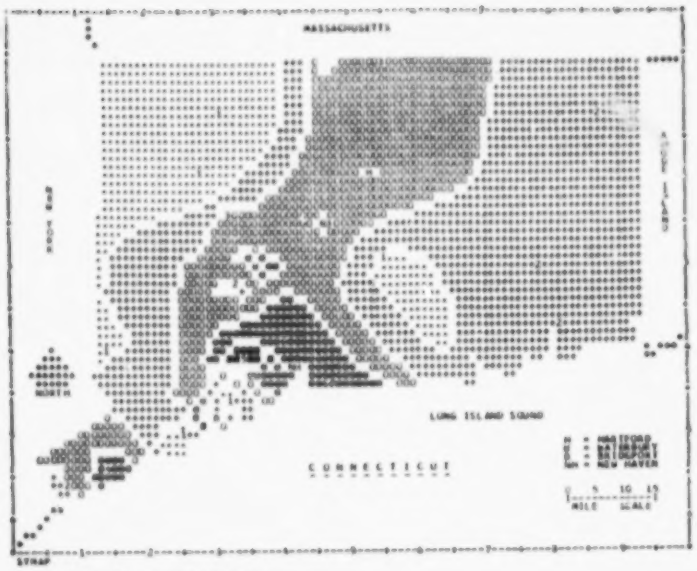


FIGURE F-1

CONNECTICUT STUDY
Connecticut Air Sampling Network
Measured Suspended Particulates Concentration
a. 1966 — 12 months b. 1968 — first 6 months

Details of illustrations in this document may be better studied on microfiche



SYMAP
C CONNECTICUT AIR SAMPLING NETWORK
C SUSPENDED PARTICULATES (UG/M3)
C 1966

DATA VALUE EXTREMES ARE 49.00 110.00

SOURCE- CONNECTICUT STATE DEPARTMENT OF HEALTH ENVIRONMENTAL HEALTH SERVICES DIVISION AVERAGE OF DAILY LEVELS

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL (*MAXIMUM* INCLUDED IN HIGHEST LEVEL ONLY)

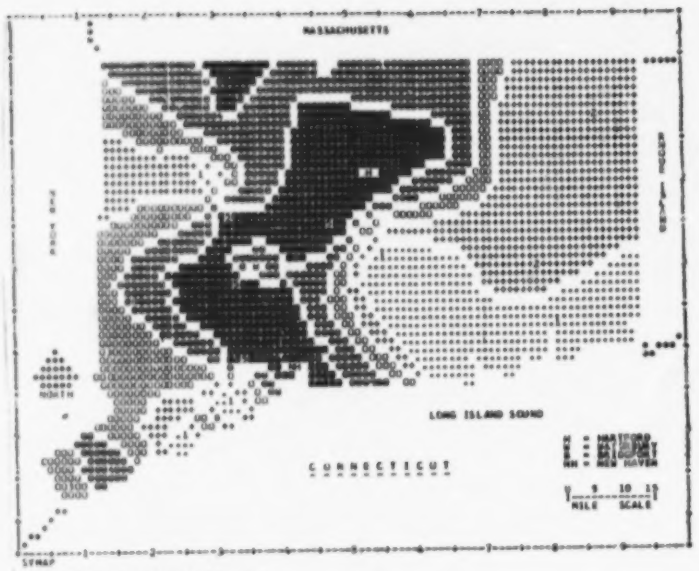
MINIMUM	49.00	59.00	69.00	79.00	89.00
MAXIMUM	59.00	69.00	79.00	89.00	110.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

	20.00	20.00	20.00	20.00	20.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5
SYMBOLS	.	2	3	4	5
FREQ.	6	4	4	3	2



SYMAP
C CONNECTICUT AIR SAMPLING NETWORK
C SUSPENDED PARTICULATES (UG/M3)
C 1967

DATA VALUE EXTREMES ARE 49.00 91.00

SOURCE- CONNECTICUT STATE DEPARTMENT OF HEALTH ENVIRONMENTAL HEALTH SERVICES DIVISION AVERAGE OF DAILY LEVELS

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL (*MAXIMUM* INCLUDED IN HIGHEST LEVEL ONLY)

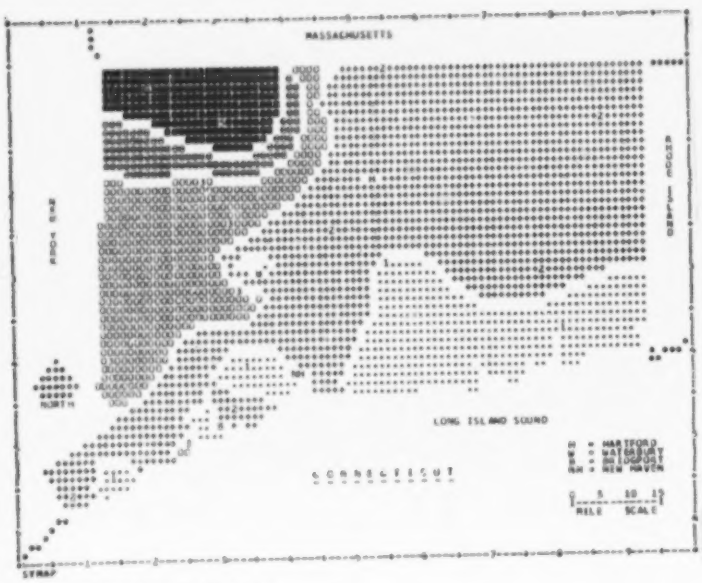
MINIMUM	49.00	57.00	65.00	73.00	81.00
MAXIMUM	57.00	65.00	73.00	81.00	91.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

	20.00	20.00	20.00	20.00	20.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5
SYMBOLS	.	2	3	4	5
FREQ.	5	2	3	4	6



SYMAP
C CONNECTICUT AIR SAMPLING NETWORK
C SUSPENDED PARTICULATES (UG/M3)
C PERCENT CHANGE 1966 - 1967

DATA VALUE EXTREMES ARE -28.00 78.00

SOURCE- CONNECTICUT STATE DEPARTMENT OF HEALTH ENVIRONMENTAL HEALTH SERVICES DIVISION AVERAGE OF DAILY LEVELS

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL (*MAXIMUM* INCLUDED IN HIGHEST LEVEL ONLY)

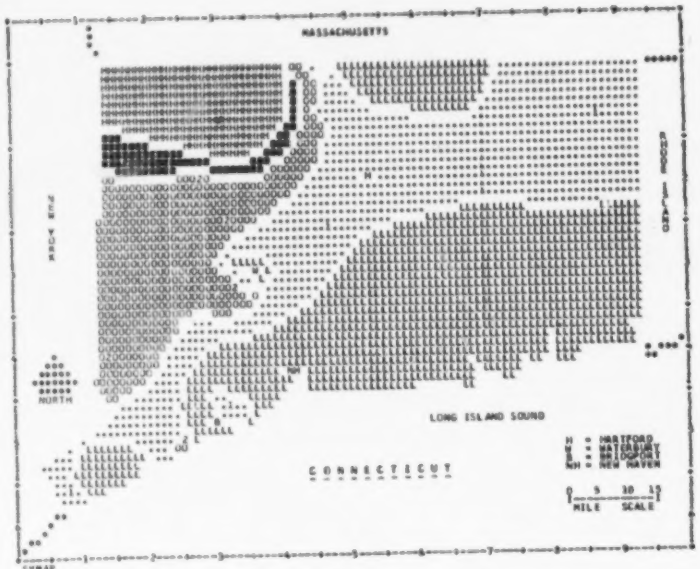
MINIMUM	-28.00	-10.00	10.00	30.00	50.00
MAXIMUM	-10.00	10.00	30.00	50.00	78.00

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

	20.00	20.00	20.00	20.00	20.00

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	1	2	3	4	5
SYMBOLS	.	2	3	4	5
FREQ.	7	7	5	2	1



SYMAP
C PERCENT INCREASE IN SUSPENDED PARTICULATES, 1966-1967
C L = LOW (BELOW ZERO) H = HIGH (ABOVE 50 PERCENT)
C 1 = 0-15 PERCENT 2 = 15-35 PERCENT 3 = 35-50 PERCENT

DATA VALUE EXTREMES ARE -28.00 78.00

SOURCE- CONNECTICUT STATE DEPARTMENT OF HEALTH ENVIRONMENTAL HEALTH SERVICES DIVISION AVERAGE OF DAILY LEVELS

ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL (*MAXIMUM* INCLUDED IN HIGHEST LEVEL ONLY)

MINIMUM	BELOW 0.00	0.00	15.00	35.00	ABOVE 50.00
MAXIMUM	0.00	15.00	35.00	50.00	

PERCENTAGE OF TOTAL ABSOLUTE VALUE RANGE APPLYING TO EACH LEVEL

	30.00	40.00	30.00		

FREQUENCY DISTRIBUTION OF DATA POINT VALUES IN EACH LEVEL

LEVEL	L	1	2	3	H
SYMBOLS	L	1	2	3	H
FREQ.	9	5	5	0	1

33

FIGURE F-2

CONNECTICUT STUDY
Connecticut Air Sampling Network
SYMAP Correspondence Course Examples
Measured Suspended Particulates Concentration

a. 1966 b. 1967
c. Percent Change — 1966 to 1967 d. Percent Change — Contour Levels Specified

Details of illustrations in this document may be better studied on microfiche

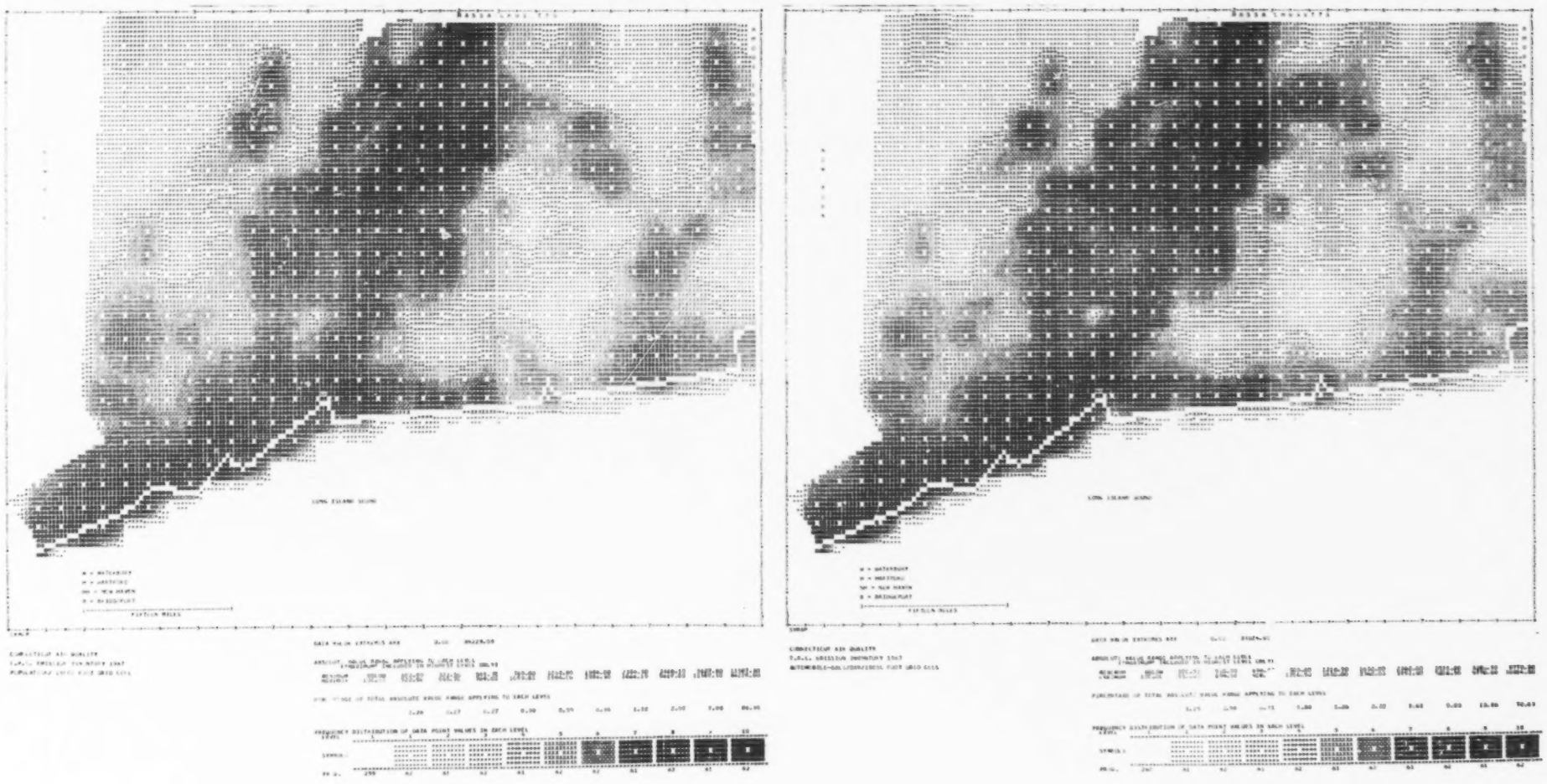


FIGURE F-3

CONNECTICUT STUDY
Travelers Research Center Emission Inventory
a. Population-related Emissions
b. Automobile-related Emissions

Digitized by the Internet Archive in 2011 with funding from Boston Library Consortium Member Libraries

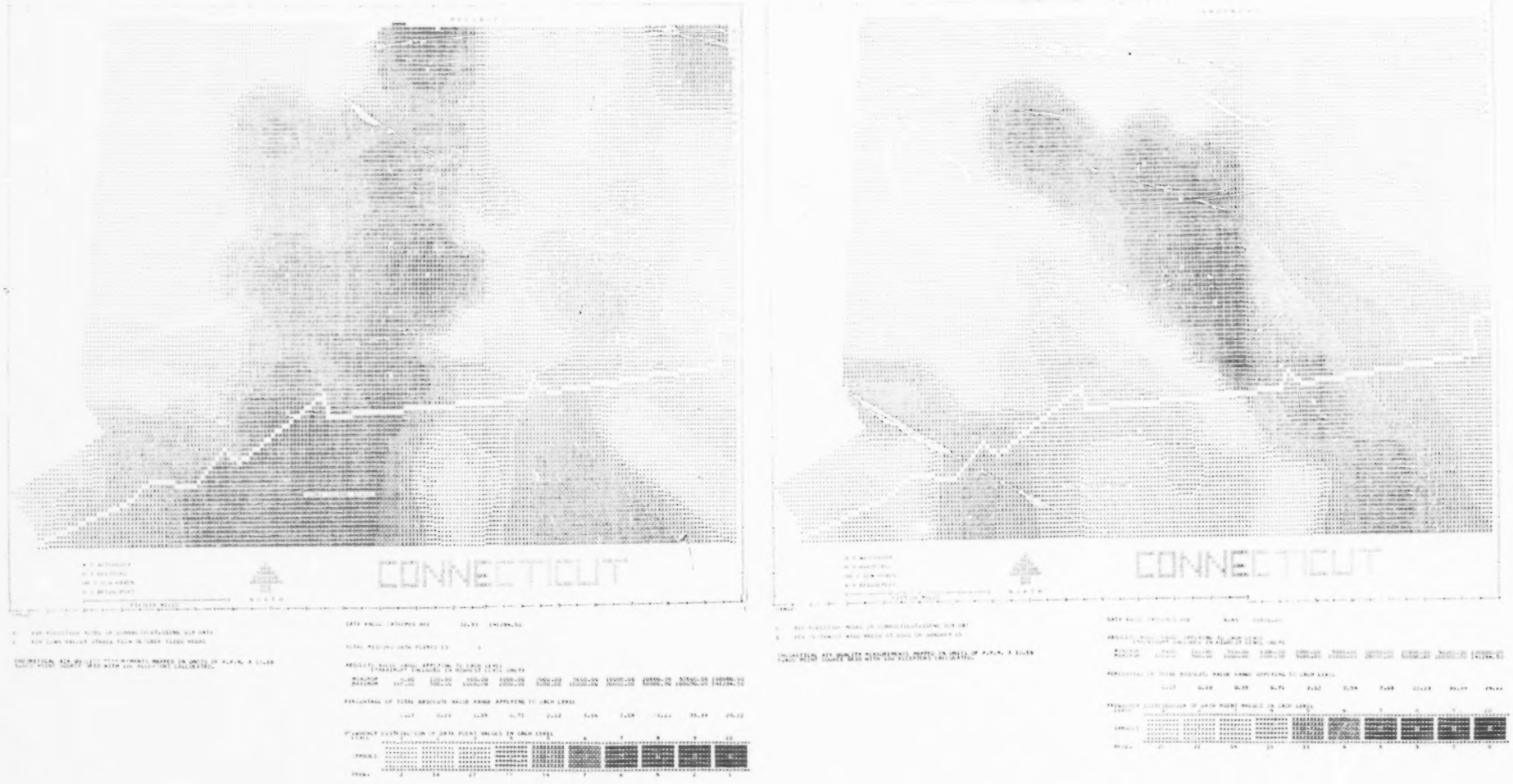


FIGURE F-4

CONNECTICUT STUDY
Travelers Research Center SOx Modeling
a. Down Valley Stable Flow — October Noon
b. Northwest Wind — January Midnight

Details of illustrations in this document may be better studied on microfiche

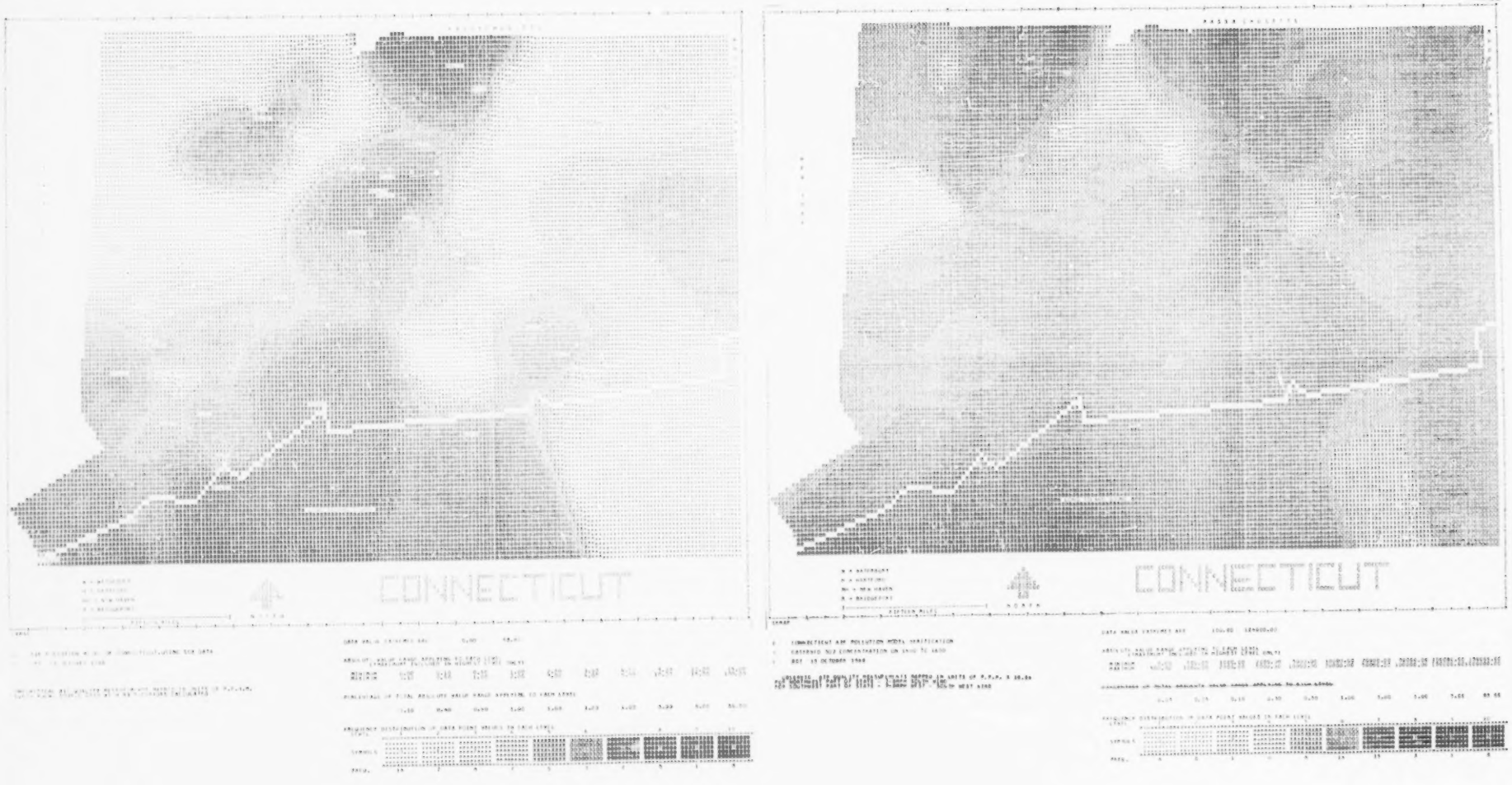
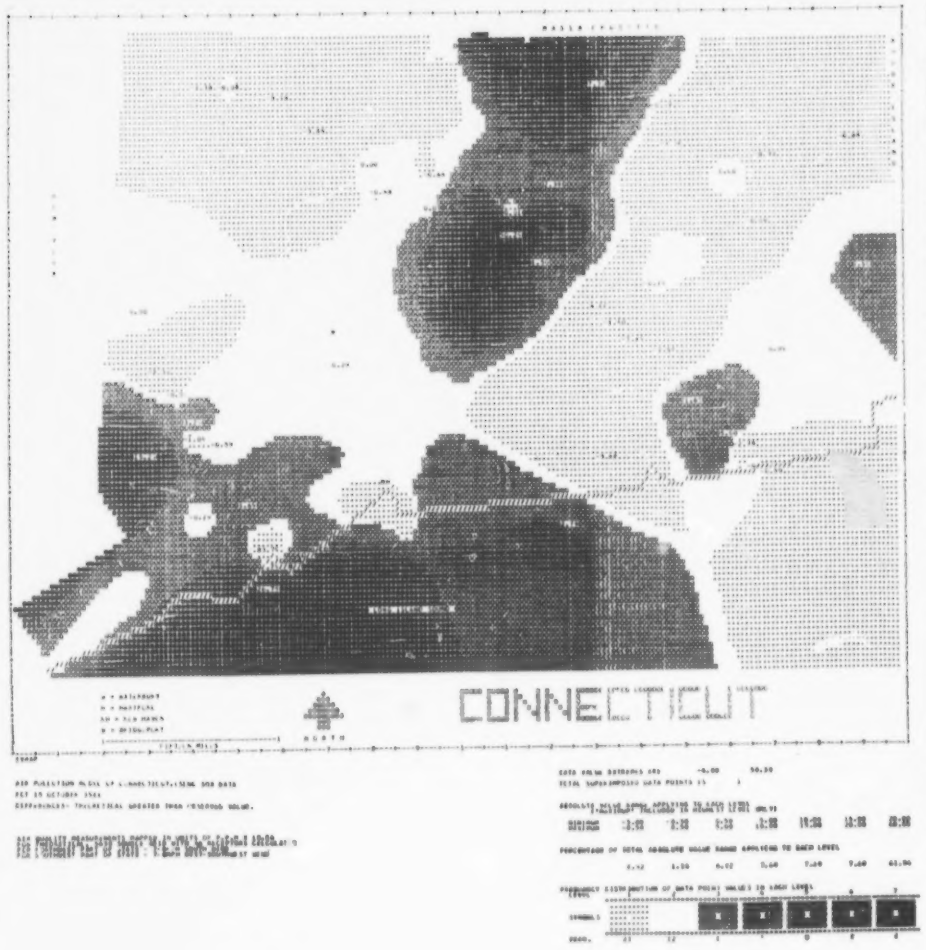


FIGURE F-5

CONNECTICUT STUDY
Travelers Research Center SOx Modeling
a. Calculated Values — October 15, 1968
b. Observed Values — October 15, 1968

Details of illustrations in this document may be better studied on microfiche



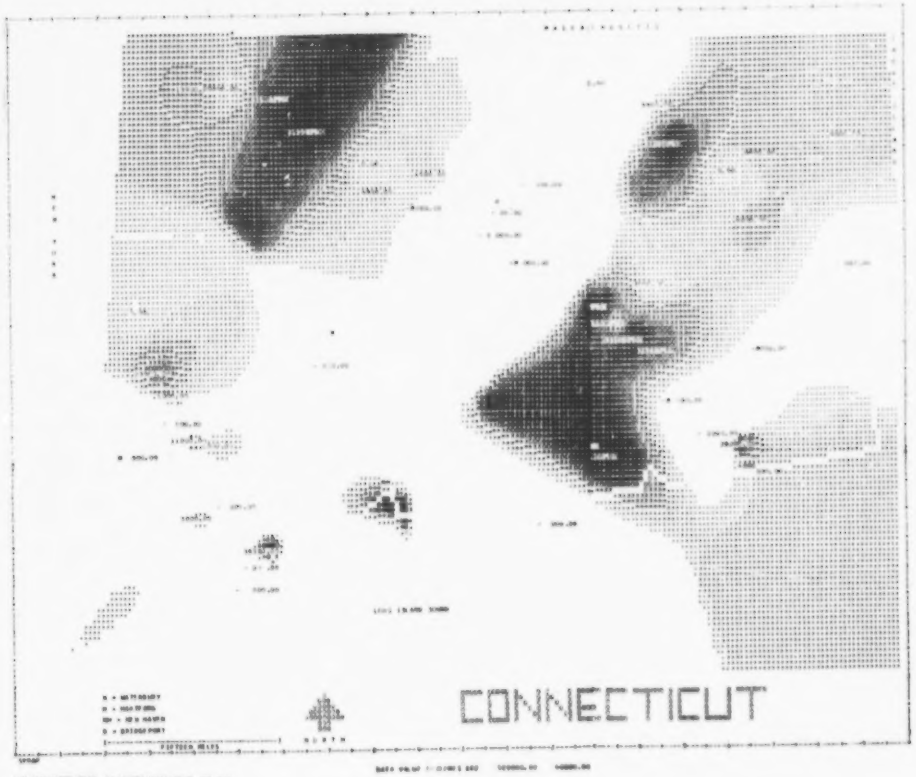


FIGURE F-6

CONNECTICUT STUDY
Travelers Research Center SOx Modeling
Values for October 15, 1968
a. Calculated Greater than Observed
b. Observed Greater than Calculated

Details of illustrations in this document may be better studied on microfiche